Efficiency of a constructed wetland for wastewaters treatment
Eficiência de um “wetland” construído no tratamento de efluentes

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Abstract: Aim: The limnological characteristics of three different inlets water of the constructed wetland were compared in terms of concentration data and loading rate data and evaluated the removal efficiencies of nutrients, solids, BOD$_5$, chlorophyll-a and thermotolerant coliforms (TC) by the treatment system; Methods: The constructed wetland, measuring 82.8 m$^2$ and with detention time of 1 hour and 58 minutes in the rainy season and 2 hours and 42 minutes in the dry one, was provided with four species, Cyperus giganteus Vahl, Typha domingensis Pers., Pontederia cordata L. e Eichhornia crassipes (Mart.) Solms. The sampling sites evaluated in the dry (D) and rainy (R) seasons were: inlet water from aquaculture farm = IA; inlet channel of rainwater runoff = IR; inlet from UASB wastewater = IB; outlet wetland = OUT. The conductivity, pH, temperature, dissolved oxygen, alkalinity, BOD$_5$, total soluble and dissolved solids, nitrogen, phosphorus, chlorophyll-a and TC were analyzed. Multivariate analyses, such as Cluster and Principal Components Analysis (PCA), were carried out to group sampling sites with similar limnological characteristics; Results: In the PCA with the concentration data was retained 90.52% variability of data, correlating the inlet IB with high concentrations of conductivity, alkalinity, pH, TC, nutrients and solids. Regarding loading rate data, the PCA was retained 80.9% of the data's total variability and correlated the sampling sites IA D, IA R and OUT R with higher BOD$_5$, chlorophyll-a, TDS, nitrate, nitrite, total-P, temperature, oxygen and water flow. The highest removal efficiencies rates occurred in the dry season, mainly in concentration, with 78% of ammonia, 95.5% of SRP, 94.9% of TSS and 99.9% of TC; Conclusions: The wetland was highly efficacious in the removal of nutrients, solids, BOD$_5$, chlorophyll-a and TC, mainly during the dry season. The system restructuring to increase the detention time during the rainy season and a pre-treatment of UASB wastewater, can increase the retention of nutrients and solids by wetland.

Keywords: constructed wetland, macrophyte, removal efficiency, hydraulic flow, loading rate.

Resumo: Objetivo: Comparar as características limnológicas de três diferentes entradas de água no “wetland” construído, com dados de concentração e carga, e avaliar a eficiência de remoção de nutrientes, sólidos, BOD$_5$, clorofila-a e coliformes termotolerantes (TC) pelo sistema de tratamento; Métodos: No “wetland” construído, com área total de 82.8 m$^2$ e tempo de residência de 1 hora e 58 minutos na estação chuvosa e 2 horas e 42 minutos na seca, foram utilizadas as espécies Cyperus giganteus Vahl, Typha domingensis Pers., Pontederia cordata L. e Eichhornia crassipes (Mart.) Solms. Os pontos de amostragem avaliados em períodos de seca (D) e chuva (R) foram: entrada de água proveniente de aquicultura = IA; canal de entrada de escoamento da chuva = IR; entrada de resíduos provenientes de biodigestores = IB; saída de água do “wetland” = OUT. As variáveis analisadas foram: condutividade, pH, temperatura, oxigênio dissolvido, alcalinidade, BOD$_5$, sólidos particulados e dissolvidos, nitrogênio, fósforo, clorofila-a e TC. Análises estatísticas multivariadas de Agrupamento e Componentes Principais (ACP) foram usadas para agrupar pontos de amostragem com características limnológicas semelhantes; Resultados: Na ACP com dados de concentração foi retido 90.52% da variabilidade dos dados, correlacionando a entrada IB com altas concentrações de condutividade, alcalinidade, pH, TC, nutrientes e sólidos. Para os dados de carga a ACP reteve 80.9% da variabilidade dos dados e correlacionou os pontos IA D, IA R e OUT R com elevada BOD$_5$, clorofila-a, STD, nitrogênio, fósforo e TC. As maiores taxas de eficiência de remoção ocorreram na seca, principalmente em concentração, com 78% para amônia, 95.5% para SRP, 94.9% para TSS e 99.9% para TC; Conclusões: O “wetland” foi eficiente na remoção de nutrientes, sólidos, BOD$_5$, clorofila-a e TC, principalmente no período seco. Reestruturações do sistema para aumentar o tempo de residência durante as chuvas e um pré-tratamento dos resíduos de biodigestores, podem aumentar a retenção de nutrientes e sólidos pelo wetland.

Palavras-chave: “wetland” construído, macrófitas aquáticas, eficiência de remoção, fluxo hidráulico, carga.
1. Introduction

Intense development in aquaculture and other agricultural and cattle-raising forms have caused an increase in environmental impacts. The culture of water organisms produces solid wastes (feed wastes, feces and others) and dissolved matter (Sindilariu et al., 2009) which are transported out of the culture system through effluents rich in organic and inorganic compounds such as ammonia, phosphorus, dissolved organic carbon and organic matter (Crab et al., 2007). All these factors may cause eutrophication and other deleterious effects in the receiving water bodies (Pistori et al., 2010; Konnerup et al., 2011).

The rapid expansion in the production of cattle has in a similar way produced a large amount of concentrated animal wastes that are dumped into the environment (Stone et al., 2004) while anaerobic digestion, such as that carried out by Upflow Anaerobic Sludge Blanket (UASB), have been employed for waste treatment (Oliveira and Santana, 2011). However, doubts exist on the capacity of the above treatment technologies to reach acceptable quality levels of the effluent especially when they are compared to aerobic processes (Von Sperling and Oliveira, 2009). Since effluents from anaerobic treatments have a large loading rate of solid and dissolved wastes from organic compounds, they should undergo a second treatment so that standards of effluent discharged in water sources could be complied with (Barros et al., 2008; An et al., 2010).

Constructed wetlands are one of the most promising methods for effluent treatment for wastewater of biodigesters and aquaculture, mainly in Brazil (Henry-Silva and Camargo, 2008; Sipaúba-Tavares and Braga, 2008; Toledo and Penha, 2011). The system is based on physical, chemical and biological processes and may deal with a great variability of pollutant load characterized by high concentration and great water flow (Brix et al., 2007; Sindilariu et al., 2009). Further, systems with ornamental macrophytes may provide a highly pleasing environment (Zurita et al., 2009).

The performance of constructed wetlands depends on microbial activity, hydraulic retention time, load, temperature and types of vegetation (El-Khateeb et al., 2009). Precipitation and evapotranspiration are some climatic factors that have an important role in the performance of treatments under tropical and subtropical conditions. During the rainy season excessive precipitation may drastically alter water levels in constructed wetlands and cause contaminant dilution and modifications in the water chemistry (Katsenovich et al., 2009).

The wetland under analysis treats not only the water from the aquaculture farm but also rainwater runoff through a channel and wastes from the animal feces-processing anaerobic biodigesters (Sipaúba-Tavares and Braga, 2008). It may be supposed that the inlets have distinct concentrations and loads and may alter the removal efficiency of wetland. Current study was aimed to i) compare the limnological characteristics of three different inlets water of the constructed wetland in terms of concentration data and loading rate data; ii) evaluate the removal efficiencies of nutrients, solids, $BOD_5$, chlorophyll-a and thermotolerant coliforms of a constructed wetland.

2. Methods

2.1. Study area

Current study was carried at the Aquaculture Center Brazil (21°15’S, 48°18’W) in a constructed wetland to treat an aquaculture effluent from a set of ponds placed in a sequence and in continuous flow. They receive water from the water source, water tanks and small ponds and from the culture sector of ornamental fish, frog and shrimps (Sipaúba-Tavares et al., 2010). The constructed wetland also receives water from surface rain runoff through a channel during the rainy season (summer) and water inlet from swine wastewater, treated in Upflow Anaerobic Sludge Blanket (UASB), with matter discharge when reactors are switched on.

The constructed wetland has a surface area of 82.8 m² and 0.30 m deep; soil consisted of eutrophic dark red latisol of a highly clayey texture; water flowed directly on the ground covered with pebbles. The system was provided with three round plastic boxes, measuring approximately 0.64 m² and 0.55 m high, with several apertures, each with 38.5 mm² diameter, at two opposite sides of the water flow. The floor of the boxes was covered with pebbles and the floating macrophyte *Eichhornia crassipes* (Mart.) Solms was placed on the water surface (Figure 1).

A plastic barrel with a lid and several side apertures for water flow, containing small plastic substrates, provided the growth of anaerobic bacteria. Two rectangle boxes, 0.18 m² and 0.30 m high, made of the same material of the other boxes and the barrel, with side apertures and filled with pebbles, were placed one near the inflow, and the
Alkalinity (Alk) was measured following techniques by MacKereth et al. (1978). Nitrate (NO$_3$), nitrite (NO$_2$), total phosphorus (TP) and soluble reactive phosphorus (SRP) by Golterman et al. (1978) and ammonia (NH$_4$) by Koroleff (1976). Chlorophyll-a (Chl-a) and thermotolerant coliforms (TC) were determined by methods following Nusch (1980) and Greenberg et al. (1992), respectively. Analyses were performed immediately after sampling or samples were duly stored under refrigeration. Air temperature and precipitation data were obtained from the Agroclimatological Station of UNESP in Jaboticabal SP Brazil, some 415 m from the experiment site.

Data on water flow rate at the inlets and outlet of the constructed wetland were obtained in triplicate in all samplings, with mean given in m$^3$.h$^{-1}$. The hydraulic loading rate (HLR) of the constructed wetland was calculated for the dry and rainy seasons by equation $q = Q/A$, where $q$ is the hydraulic loading rate (HLR) (m.h$^{-1}$); $Q$ is the water flow rate (m$^3$.h$^{-1}$) and $A$ is the wetland area (wetland land area) (m$^2$). Detention time for the two seasons was measured by equation $T_r = V/Q$, where $T_r$ is the detention time (hours); $V$ is the maximum volume of the channel (m$^3$) and $Q$ is the water flow rate (m$^3$.h$^{-1}$). The loading rate was calculated from each inlet and outlet of the constructed wetland by equation $m = q.C$ where $m$ is the (specific) loading rate (g.m$^{-2}$.d$^{-1}$); $q$ is the hydraulic loading rate (HLR) (m.h$^{-1}$) and C is the concentration (mg.m$^{-3}$). The removal percentage of nutrients, solids, BOD$_5$, chorophyll-a and TC by the constructed wetland was measured by the formula: % removal efficiency = ([Σm$_i$-m$_o$]/Σm$_i$].100, where Σm$_i$ is the sum of inlets of loading rates or concentrations and m$_o$ is the outlet of loading rates or concentrations.

other close to the water outflow, to slow the velocity of the water and enhance the growth of periphyton adhered to the stones (Figure 1).

Whereas *Cyperus giganteus* Vahl and *Typha domingensis* Pers. were planted close to the inflow channel, *Pontederia cordata* L. was planted at a distance of approximately 25 m from the effluents inflow, close to a shaded area. The planted area was equivalent to 43.5% of the channel's total area (Figure 1).

2.2. Sampling and analyses

Water samplings for the determination of limnological characteristics were undertaken always in the morning during six months at two climatic periods. The first period was between January to March 2008 (n = 6) during the rainy season and the second period was between June to August 2008 (n = 8) during the dry season. Samples were taken regularly at the water surface and 10 cm from the inlet channels and outlet wetland. The sampling sites evaluated were: inlet water from aquaculture farm = IA R (rainy season) and IA D (dry season); inlet channel of rainwater runoff = IR (only during the rainy season, because there were no runoff during the dry season); inlet from UASB wastewater = IB (only during the dry season, since no discharge occurred during the rainy season); outlet wetland = OUT R (rainy season) and OUT D (dry season).

Conductivity (Cond), pH and water temperature (°C) were measured in situ with a portable meter Horiba U-10, and dissolved oxygen (DO) with a handheld dissolved oxygen meter YSI-55. Total soluble solids (TSS), total dissolved solids (TDS) and biochemical oxygen demand (BOD$_5$) were determined according to Boyd and Tucker (1992).
2.3. Statistical analysis of data

Concentration data and loading rate data were submitted separately to Multivariate Cluster Analysis performed by Ward’s method and the similarities-dissimilarities quantified through Euclidean distance measurements to sort sampling sites into groups with strong degree of association between members of the same cluster. To clarify the correlation between the limnological variables and clustering sampling sites was performed two Principal Component Analysis (PCA) for concentration data and loading rate data, to reduce the data dimensionality in two bi-dimensional graphs (Kindt and Coe, 2005). Only components with eigenvalues higher than 1 were analyzed, following Kaiser Normalization criterion (1958). The concentration data and the loading rate data were evaluated separately to identify data patterns according to the variation of the water flow in the constructed wetland. The statistical analyses were carried out by Statistica 8.0 (STATSOFT, 2007).

3. Results

Rates of flow and hydraulic loading during the rainy season were higher than those during the dry one, respectively 41.6 m³.h⁻¹ to 30.6 m³.h⁻¹ and 0.50 m.h⁻¹ to 0.37 m.h⁻¹. On the other hand, rates for detention time were 2 hours and 42 minutes during the dry season and 1 hour and 58 minutes during the rainy one. Monthly mean for air temperature and water temperature were higher during the rainy season (summer), with 23.5 °C and 26.7 °C and in the dry season at 20.1 °C and 19.8 °C, respectively. The precipitation mean between January to March was 245.4 mm and between June to August was 11.8 mm (Figure 2).

The Cluster Analysis with the concentration data of water variables showed that sampling sites constituted three main groups. Cluster I consisted of sites IA D and OUT D; cluster II comprised sites collected during the rainy season, namely, IA R, OUT R and IR; cluster III was only made up by site IB (Figure 3). In the Analysis of Principal Components with the concentration data of variables only the first two axes were taken into account. In fact, they comprised 90.52% of total data variability where axis 1 was related to the wetland’s water quality which explained 78.40% of the original variability data. According to cluster analysis, group II was negatively bound to this axis and associated with high temperature, water flow, high concentrations of chlorophyll-a and BOD₅, mainly at the sites which correspond to water inflows wetland. Highest concentrations in ammonia, nitrite, SRP, Total P, TDS, TSS, TC, conductivity, alkalinity and pH were positively related to axis 1, similar to IB. Axis 2 of the Principal Components Analysis had 12.1% of the original variability data. Dissolved oxygen, nitrate, pH and low temperatures were positively related to this axis and characterized group I of the Cluster Analysis. In short, data from Cluster Analysis from Principal Components Analysis showed that inflow IB was the site with the highest concentration of nutrients, solids and TC (Figure 3).

Regarding loading rate data of the limnological variables, the Cluster Analysis also grouped the sampling sites in three main groups. Cluster I consisted of sites IA D, IA R and OUT R, whereas cluster II comprised sites OUT D and IR and cluster III included only site IB (Figure 4). Only the first two axes of the Principal Components Analysis with loading rate data were employed.

Figure 2. Seasonal variation of average monthly precipitation (mm) during the experimental period.
II with high TSS and low Total P and SRP loading rates (Figure 4). The variables pH and conductivity showed a similar behavior with higher averages were only collected at sites during the dry season, especially in the IB. Alkalinity was also higher at this site and lowest at IR. However, dissolved oxygen had the highest concentration at the site IA D and the lowest at the site IB (Table 1).

since they had 80.9% of the data’s total variability. High temperature, dissolved oxygen, water flow, BOD₅, chlorophyll-a, TDS, nitrate, nitrite and Total P in axis 1 (57.2%) were negatively related and characterized group I of Cluster Analysis. On the other hand, site IB was positively characterized to this axis by high pH, conductivity, alkalinity, SRP and thermotolerant coliforms. Axis 2 with data variance of 23.7% positively correlated group II with high TSS and low Total P and SRP loading rates (Figure 4).

The variables pH and conductivity showed a similar behavior with higher averages were only collected at sites during the dry season, especially in the IB. Alkalinity was also higher at this site and lowest at IR. However, dissolved oxygen had the highest concentration at the site IA D and the lowest at the site IB (Table 1).
Table 1. Seasons means and standard deviation of abiotic variables of the sampling sites. IA: Inlet water from aquaculture farm; IR: inlet channel of rainwater runoff; IB: inlet from UASB wastewater; OUT: outlet wetland; Cond: Conductivity; DO: Dissolved Oxygen; Alk: Alkalinity.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Dry</th>
<th>Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IA</td>
<td>IB</td>
</tr>
<tr>
<td>pH</td>
<td>8.3 ± 0.1</td>
<td>10.0 ± 0.5</td>
</tr>
<tr>
<td>Cond (µS.cm⁻¹)</td>
<td>108.3 ± 6.6</td>
<td>2328.6 ± 1315.9</td>
</tr>
<tr>
<td>DO (mg.L⁻¹)</td>
<td>8.0 ± 1.1</td>
<td>2.6 ± 2</td>
</tr>
<tr>
<td>Alk (mg.L⁻¹)</td>
<td>76.3 ± 28</td>
<td>889.2 ± 1603.6</td>
</tr>
<tr>
<td>Flow (m³.h⁻¹)</td>
<td>30.6 ± 7.5</td>
<td>1.4 ± 0.1</td>
</tr>
</tbody>
</table>

High means concentrations for nitrite, ammonia, SRP, Total P, TSS, TDS and TC were found at inlet IB. Nitrate had the highest concentrations during the dry season, principally at the inlet site IA D, whereas BOD₅ was highest during the rainy season, especially at IA R. Further, IA D and IA R were the sites with the highest concentrations of chlorophyll-a (Table 2).

Loading rate data for nitrate and TDS were higher for sampling sites IA D and IA R, whereas for ammonia, BOD₅, and chlorophyll-a were highest only for IA R. Nitrite had higher loading rates not only at IA D and IA R but also at OUT R. IB was the main inlet of SRP loading rate whereas IA D and IB were the highest means for Total P. Sampling sites had higher rates for TSS during the rainy season than those collected during the dry one (Table 2).

Highest removal efficiencies rates from concentration and loading rate data occurred during the dry season with the exception of concentration data for BOD₅ and chlorophyll-a, which were highest during the rainy season. When removal efficiencies rates between concentration and loading data during the dry season were compared, highest removal rates were found in the concentration of nitrite, ammonia, SRP, Total P, TSS and TDS; in the case of loading rate data the highest were for variables BOD₅, nitrate and chlorophyll-a. Only nitrite, SRP, Total P and TSS had the highest removal efficiencies rates in concentration data during the rainy period. All the other variables had the highest removal rates for loading data in this season (Table 2).

4. Discussion

Hydraulic loading rate and water temperature characteristics followed the regional seasonal trends. According to Tanner (1996), the climate of the place where the assay was conducted is extremely important in the effluent treatment systems since it affects the biological processes that regulate nutrient removal in the wetlands. Precipitation affects detention time and, consequently, influences the nutrients and solids removal efficiencies in the wetlands (Kuschk et al., 2003), as current investigation shows.

Variation in water volume and flow are factor that may affect the amount of pollutants discharged into the treatment system and capacity to remove the compounds. Although UASB wastewater had higher concentrations of nitrogen, phosphorus and solids, the loading rate data, which were influenced by water volume, indicated that effluents with greater flow, such as inlet water from aquaculture farm (dry and rainy season) can cause a faster degradation process of water quality in receiving water bodies.

The inlet water from aquaculture farm had high concentrations only for TSS and BOD₅, in the rainy season due to allochthonous particles and sediment re-suspension caused by rain. In the case of other variables analyzed in this sampling site, rain was a dilution factor since concentrations were equal or less that those during the dry season.

Loading rate data, however, showed that inlet water from aquaculture farm for the two climatic periods and the outlet water wetland during the rainy season mainly caused the high loading rate of all forms of inorganic nitrogen, Total P, TDS, BOD₅, chlorophyll-a and DO, mainly due to the high flow from the ponds of the water organisms production system. These sites, especially during the rainy season, had the worst water quality owing to the high discharge of large quantities of organic particles to the constructed wetland and to reduced retention time in the system which affected the removal efficiency. Filtration, sedimentation, adsorption, inactivation and microbial metabolism processes were the main mechanisms that decreased rates of the variables BOD₅, chlorophyll-a, TSS, TDS, Total P, nitrogen and TC (Boutilier et al., 2009). Akratos et al. (2008) and Sindilariu et al. (2009) reported that greater detention time water in constructed wetlands was the most important positive factor in pollutants removal efficiency.
Table 2. Seasons means and standard deviation of concentration data (mg.L$^{-1}$), loading rate data (g.m$^{-2}$.d$^{-1}$) and removal efficiency (ER %) of nutrients, solids, BOD$_5$, chlorophyll-a and thermotolerant coliforms (TC) of the sampling sites. IA: Inlet water from aquaculture farm; IR: inlet channel of rainwater runoff; IB: inlet from UASB wastewater; OUT: outlet wetland.

<table>
<thead>
<tr>
<th></th>
<th>Dry</th>
<th>Rain</th>
<th>ER (%)</th>
<th>Dry</th>
<th>Rain</th>
<th>ER (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IA</td>
<td>IB</td>
<td>OUT</td>
<td>ER (%)</td>
<td>IA</td>
<td>IR</td>
</tr>
<tr>
<td>Concentration (mg.L$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td>1.4 ± 0.4</td>
<td>1.2 ± 0.7</td>
<td>1.1 ± 0.4</td>
<td>55.3</td>
<td>0.8 ± 0.4</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>Nitrite</td>
<td>0.03 ± 0.005</td>
<td>0.2 ± 0.2</td>
<td>0.03 ± 0.01</td>
<td>84.9</td>
<td>0.02 ± 0.01</td>
<td>0.02 ± 0.03</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.1 ± 0.05</td>
<td>1.2 ± 0.7</td>
<td>0.3 ± 0.2</td>
<td>78.0</td>
<td>0.1 ± 0.04</td>
<td>0.1 ± 0.08</td>
</tr>
<tr>
<td>SRP</td>
<td>0.1 ± 0.03</td>
<td>3.4 ± 1.9</td>
<td>0.2 ± 0.1</td>
<td>95.5</td>
<td>0.1 ± 0.04</td>
<td>0.2 ± 0.1</td>
</tr>
<tr>
<td>Total P</td>
<td>0.3 ± 0.1</td>
<td>3.8 ± 3.1</td>
<td>0.4 ± 0.2</td>
<td>91.0</td>
<td>0.1 ± 0.03</td>
<td>0.2 ± 0.2</td>
</tr>
<tr>
<td>TSS</td>
<td>10.9 ± 5.5</td>
<td>348.8 ± 250</td>
<td>18.3 ± 25.6</td>
<td>94.9</td>
<td>19.5 ± 3.8</td>
<td>83.0 ± 59.9</td>
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<td>TDS</td>
<td>183.9 ± 96.9</td>
<td>956.0 ± 928.9</td>
<td>165.1 ± 60.2</td>
<td>85.5</td>
<td>153.7 ± 91.8</td>
<td>115.5 ± 72.6</td>
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<td>BOD$_5$</td>
<td>5.7 ± 0.8</td>
<td>3.0 ± 2.7</td>
<td>6.1 ± 1.5</td>
<td>29.5</td>
<td>7.1 ± 1.4</td>
<td>6.2 ± 2.6</td>
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<tr>
<td>Chlorophyll-a</td>
<td>0.04 ± 0.03</td>
<td>0.02 ± 0.04</td>
<td>0.02 ± 0.05</td>
<td>69.8</td>
<td>0.05 ± 0.02</td>
<td>0.02 ± 0.01</td>
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<tr>
<td>TC (NMP.100 mL$^{-1}$)</td>
<td>11.3 ± 19.5</td>
<td>1.74 × 10$^2$ ± 3.83 × 10$^7$</td>
<td>775.9 ± 1959</td>
<td>99.9</td>
<td>65.8 ± 75.5</td>
<td>1790 ± 2452</td>
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<tr>
<td>Loading rate (g.m$^{-2}$.d$^{-1}$)</td>
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<td></td>
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<tr>
<td>Nitrate</td>
<td>12.3 ± 5.1</td>
<td>0.5 ± 0.3</td>
<td>3.0 ± 1.3</td>
<td>76.9</td>
<td>9.1 ± 5.4</td>
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<tr>
<td>Nitrite</td>
<td>0.3 ± 0.1</td>
<td>0.1 ± 0.1</td>
<td>0.1 ± 0.03</td>
<td>72.9</td>
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<tr>
<td>Ammonia</td>
<td>0.8 ± 0.4</td>
<td>0.5 ± 0.3</td>
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<td>43.7</td>
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<td>78.5</td>
<td>0.8 ± 0.7</td>
<td>0.4 ± 0.3</td>
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<tr>
<td>Total P</td>
<td>2.2 ± 1.2</td>
<td>1.6 ± 1.3</td>
<td>1 ± 0.6</td>
<td>72.9</td>
<td>1.2 ± 0.6</td>
<td>0.8 ± 0.8</td>
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<td>TSS</td>
<td>100.4 ± 67.0</td>
<td>148.3 ± 113.5</td>
<td>40.8 ± 49.6</td>
<td>83.6</td>
<td>243.0 ± 91.0</td>
<td>282.2 ± 284.1</td>
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<tr>
<td>TDS</td>
<td>1532 ± 673.8</td>
<td>392.4 ± 381.0</td>
<td>423.1 ± 193.1</td>
<td>78.0</td>
<td>1952 ± 1296</td>
<td>333.6 ± 237.2</td>
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<td>BOD$_5$</td>
<td>49.1 ± 7.7</td>
<td>1.2 ± 1.1</td>
<td>15.3 ± 4.6</td>
<td>69.5</td>
<td>86.2 ± 27.9</td>
<td>18.6 ± 11.8</td>
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<tr>
<td>Chlorophyll-a</td>
<td>0.4 ± 0.4</td>
<td>0.01 ± 0.02</td>
<td>0.1 ± 0.1</td>
<td>73.0</td>
<td>0.7 ± 0.3</td>
<td>0.04 ± 0.03</td>
</tr>
</tbody>
</table>
Current study showed that high water inflow in the system due to the rainy season made difficult the filtration and sedimentation of particles and the metabolism of the microbial community. This fact caused less efficiency in the rate decrease of loading rate variables when compared to the dry season.

During the rainy season the sampling site IR was the inflow with the highest concentrations in ammonia, SRP, Total P, TSS and TC, with an increase of concentrations in the water of the constructed wetland. Undoubtedly this fact made the treatment by the system more difficult during the rainy season. Inlet channel of rainwater runoff also contributed towards TSS high loading rate which might have affected the low performance of treatment during the period. In fact, organic and suspended solids loading rates were the main parameters that influenced the treatment’s obstruction process (Dahab and Surampalli, 2001). As a consequence, TC increased at the outlet wetland during the rainy season. This was probably due to a higher concentration of nutrients and solids with the same pattern. In fact, nutrients provided resources for the metabolism of microorganisms and rates of suspended solids increased the survival of bacteria (Boutilier et al., 2009).

The UASB wastewater had the highest concentration of nutrients and organic matter. Despite anaerobic biodigestion is an alternative method for the treatment of animal wastes, it has been reported that effluents from UASB contain organic and inorganic compounds and pathogenic microorganisms at concentrations which are higher than standards recommended for the elimination in water sources (Kaseva, 2004), as occurred in this study. Further treatments are required before wastes reached the wetland under analysis so that the water outflow of the treatment might be reused.

Thermotolerant coliforms had a higher rate only at IB, since biodigesters used cattle, pig and fowl feces rich in TC as reaction materials. Cattle feces have been identified as the main reservoir of Escherichia coli, a highly potent transmission vector to the environment, animals and food (Wang et al., 1996). Amaral et al. (2004) verified that biodigesters significantly decrease total and thermotolerant coliforms in the anaerobic biodigestion process in reactors in India and China, even though they still exhibited high rates of TC in the effluent.

The removal of TC by constructed wetland system occurs by the presence of macrophytes, which reduce the number of pathogenic bacteria due to the excretion of inhibiting metabolites and the stimulation of preying microorganisms in the rhizosphere (Kouki et al., 2009). In this study, the high removal rate of TC observed during the dry season may be attributed to presence of macrophytes and dilution by wetland water, which better performance due to hydraulic characteristics of the period.

Owing to the biodigestion process of animal-originated organic material, IB caused high pH, conductivity and alkalinity, coupled to low rates in DO and BOD, in the concentration and loading rate analysis. Low rates were the consequence of anaerobic treatment in the biodigesters in which DO concentrations were reduced with the subsequent aerobic decomposition of organic material.

The pH was alkaline with higher rates during the dry season, mainly at the inlet from UASB wastewater. According to Maine et al. (2007), water with high pH might limit the growth of E. crassipes. In this study the water alkaline might have impaired the E. crassipes performance in the treatment. Aquatic macrophytes in water wetlands with high pH mainly provided a substratum so that the decomposing microorganisms raised free carbon dioxide rate in the column water (Mayes et al., 2009). The CO2 from the respiration of microorganisms in the constructed wetland might have helped in the decrease of pH at the outlet.

Low water volume in the constructed wetland during the dry season increased conductivity of the entire system. This fact was due to high pH caused by high concentrations of hydroxyls in the environment, carbonates, bicarbonates, sulfates, ammonia and other ions from the biodigestion of organic matter, especially after the inlet from UASB wastewater. High alkaline water wetland may have been related to the high presence of calcium compounds, because according to Mayes et al. (2009) the hydrolysis of calcium compounds produces the hydroxyl ion, which elevates solution pH and releases Ca2+ ions in the wetland. A decrease in conductivity was reported during the dry season, probably due to the dilution of the compounds in the wetland water and to the assimilation and metabolism of calcium, magnesium, potassium, sodium and other ions by the microorganisms and plants in the wetland.

Removal of phosphorus compounds during the rainy season and mainly during the dry one was related to the alkalinity of water and to absorption by macrophytes. Due to DO concentration increase at the outlet wetland, a high potential redox might
have occurred with the adsorption of phosphorus and iron hydroxides, and their fixture on the sediment. Main et al. (2007) also reported this type of process.

Intensification of nitrification and denitrification occurred at the 6.5-8 pH range (Tao and Wang, 2009) and intensification of the volatilization of ammonia with pH over 8.5 (Vymazal, 2007). Current study evidenced nitrogen decrease during the dry season which occurred through the absorption by plants and microorganisms and by the loss of nitrogen in the atmosphere. DO highest concentrations at IA D and OUT D might be associated to a greater transparency of the water column which allowed greater light penetration and promoted the photosynthesis of algae, and thus affecting nitrification rates. High DO in wetlands causes the nitrification process through a decrease in ammonia levels and an increase of nitrates (Faulwetter et al., 2009). Whereas nitrifying bacteria also to use CO₂ and bicarbonate for cell synthesis, they also employ ammonia and nitrite as energy sources, with the consequent reduction of these compounds in the water column (Spieles and Mitsch, 2000).

As a rule, in current study water treatment was positively affected by detention time. Best removal efficiency during the dry season was similar to that of other researchers conducted in tropical climates (Olguín and Sánchez-Galván, 2010), although hydraulic loading rate in the wetland under analysis was higher.

In summary, the results showed the relevance of concentration and loading rate data analysis. Although inlet from UASB wastewater had the greatest concentrations for most variables, the inlet water from aquaculture farm greatly contributed towards the degradation process of the source in the two climatic periods when flow was taken into account. Rain diluted the compounds from the two climatic periods when flow was taken into account. Rain diluted the compounds from the two climatic periods when flow was taken into account. Rain diluted the compounds from the two climatic periods when flow was taken into account.

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